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ON

EXPLOSIVES.

BY

WALTER N. HILL, S. B.,
Chemist, U. S. Torpedo Station.

1875.

PROVIDENCE
ATHENÆUM.

NOTES

ON

EXPLOSIVES,

AND THEIR APPLICATION IN

TORPEDO WARFARE.

BY

WALTER N. HILL, S. B.,
Chemist, U. S. Torpedo Station.

U. S. Torpedo Station,
Newport, Rhode Island, 1875.

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PREFACE.

The following pages are mainly taken from the notes of a course of lectures on explosives, delivered at the Torpedo Station during 1874. The subject is too large and too detailed to receive anything like an extended treatment in the limited space that can now be devoted to it. Therefore, only some of the more prominent topics will be briefly touched upon in some of their practical bearings, and particularly those related to torpedo warfare. In this connection the detonating explosives (nitro-glycerine and gun-cotton) are of the greatest importance, as they have come into extensive use, and will probably be largely applied to torpedo purposes, while they are yet unfamiliar to many persons. Especial attention will, consequently, be paid to them, after a short discussion of the general principles governing all explosions.

In conclusion, some points connected with the application of explosives to torpedoes will be taken up.

Considerable space will be given to details of some operations in use and experiments performed at the Torpedo Station. They have not been described before, and may possess some points of interest. Of course, it has not been possible to undertake at the Station extensive experiment with all explosives, but some of the results of experiment may be of value as far as they go.

Those who wish to study the subject of explosive agents minutely can consult works on chemical technology and a few special books, but, to a large extent, the literature of the subject is to be found in scientific and technical periodicals, and in occasional publications of various kinds.

Professor Hill - left the employ of the U. S. + engaged with the Ramapo (?) Powder Co., in the laboratory of which he was soon killed with several other men - in a terrible explosion due to carelessness of an assistant -

NOTES ON EXPLOSIVES AND THEIR APPLICATIONS IN TORPEDO WARFARE.

EXPLOSIVE REACTIONS.

All chemical changes, whether of combination or decomposition, are called reactions.

Reactions take place in or between molecules. The same atoms are found after a reaction as were present before, but differently arranged or united, forming molecules different from those which entered into the reaction. The reaction, then, is a change in the manner in which the attractions or affinities of the atoms are exerted. The operations of these attractions are governed by the circumstances under which they are exercised. Then, in order to produce any desired result, certain necessary conditions must be fulfilled.

These conditions vary between extreme limits. Thus, in one compound, the attractions which bind together its parts may be so feebly exercised that the slightest change in its surrounding circumstances will bring about its decomposition, while to reverse those of another compound may require that the most powerful agencies should be exerted for a long time. Again, compounds which are stable at the ordinary temperature, may be broken up when moderately heated, or reactions which occur at the ordinary pressure, may be entirely altered if the same materials are brought together at a different pressure.

Reactions may go on rapidly or slowly, and be accompanied by evolution of gas, of heat, light, electricity, &c. When these accompaniments are of a certain kind explosive effect results, and we have *explosive* reactions, but such chemical changes are governed by the same laws as all reactions.

DEFINITION OF EXPLOSION.

The term explosion is rather loosely used. Considering it as synonymous with explosive reaction, it may be defined as a chemical action, causing the sudden or extremely rapid formation of a very great volume of highly expanded gas.

EXPLOSIVE EFFECT.

Explosive effect is caused by the blow or impulse given by this rapid production of gas in a confined space.

The explosive character of the change, then, depends—

1st. Upon the great change of state produced, that is, the formation of gas very much greater in volume than the substance from which it is derived, and which is still more expanded by the heat evolved.

2d. Upon the shortness of the time required for the change to take place.

Both these causes operate to a greater or less extent in all explosive reactions. When both are fully exerted the most energetic chemical reaction, or, in other words, the most violent explosion takes place. Also, the differences in explosions and explosive bodies depend upon the differing manner and proportions in which they are exerted. Thus, nitro-glycerine is much more powerful and violent than gunpowder, because it generates a larger volume of gas in a shorter time. Again, fulminating mercury is not more powerful than gunpowder, although the decomposition goes on more quickly, since the quantity of gas given off, and the temperature of the reaction are less.

The kinds and quantity of gas given off in an explosive reaction depend upon the chemical composition of the explosive body and the character of the decomposition.

The heat evolved during the reaction adds to the effect by increasing the tension (expanding the volume) of the gas formed. The heat given off in a reaction is an absolute quantity, the same whether the reaction goes on slowly or rapidly. But the *explosive* effect will evidently greatly depend upon the *rapidity* of the formation and expansion of the gas. Thus, if an explosive undergoes the same change under all circumstances of firing, then the total amount of force developed will always be the same, but the *explosive effect* will be increased as the time of action is lessened.

CIRCUMSTANCES OF EXPLOSION.

Explosions are greatly affected by the circumstances attending them. Different substances, of course, give different results, from their different compositions and reactions. But we also find that the same substance will exercise a different explosive effect when fired under certain conditions than under others. These may affect either the rapidity or the results of the chemical change. By shortening the time of the reaction the explosion is rendered sharper and more violent. With some explosives, the decomposition is different under different circumstances. Thus, gunpowder, when fired under great pressure, as in a mortar, gives different products than when fired unconfined.

Circumstances of explosion may be generally considered under—

1st. Physical or mechanical condition of the explosive body itself.
2d. External conditions.
3d. Mode of firing.

1st. Physical or mechanical condition of the explosive body.

Many instances may be given indicating the influence of its state upon the explosion of a substance. Thus, nitro-glycerine at temperatures above 40° Fah. is a liquid, and in the liquid condition may be violently exploded by a fuse containing 15 grains of fulminating mercury.

Below 40° it freezes and cannot be so fired.

The advantage of dynamite over nitro-glycerine lies altogether in the fact that the latter is presented in another mechanical condition, more convenient and safer to use than the liquid form. The nitro-glycerine itself is the same chemically in either case. The same mixture of charcoal, sulphur, and saltpetre gives a very different effect if made up into large grains than if made up into small ones. Gun-cotton presents the most marked example of the effect of mechanical state, since it can be prepared in so many ways.

If flame is applied to loose uncompressed gun-cotton it will flash off; if it is spun into threads or woven into webs, its rate of combustion may be so much reduced that it can be used in gunnery or for a quick fuze; powerfully compressed and damp, it burns slowly; dry gun-cotton may be exploded by a fulminate fuse; wet, it requires an initial explosion of a small amount of dry, &c.

2d.—*External conditions.*

Confinement is necessary to obtain the full effect of all explosives. The most rapid explosion requires a certain time for its accomplishment. As the time required is less, the amount of confinement necessary is less. Then with the sudden or violent explosives, the confinement required may be so small that its consideration may be practically neglected. For instance, large stones or blocks of iron may be broken by the explosion of nitro-glycerine upon their surfaces in the open air. Here the atmosphere itself acts as a confining agent. The explosion of the nitro-glycerine is so sudden that the air is not at once moved.

Again, chloride of nitrogen is one of the most sudden and violent of all explosives. In its preparation it is precipitated from a watery liquid, and therefore is, when used, wet or covered with a very thin film of water. This thin film of water, not more than 1-1000th of an inch in thickness, is a necessary and sufficient confinement, and if it is removed the explosive effect is much diminished.*

Gunpowder, on the other hand, requires strong confinement, since its explosion is comparatively slow. Thus, in firing a large charge of gunpowder under water, unless the case is strong enough to retain the gases until the action has become general, it will be broken, and a large amount of the powder thrown out unburned. This is often the case in firing large-grained powder in heavy guns. The ball leaves the gun before all the powder has burned, and grains or lumps of it are thrown out uninjured.

The confinement needed by the slower explosives may be diminished by igniting the charge at many points, so that less time is required for its complete explosion.†

3d.—*Mode of Firing.*

In any explosive reaction the mode of bringing about the change exercises an important influence. The application of heat, directly or indirectly, is the principal means of causing an explosion. Thus in gunnery, the flame from the percussion cap or primer directly ignites the charge; so also a fine platinum wire heated by an electric current will ignite explosive material, which is in contact with it. Friction, percussion, concussion, produce the same effect indirectly, by the conversion of mechanical energy into heat, which is communicated to the body to be exploded.

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* Abel, Trans. Roy. Soc., 1869, 489.

† Thus, in the spar torpedo issued from this station, only one fuse is used, but this is placed in the hollow spindle which traverses the centre of the torpedo, and which is pierced with many holes, through which the flame from the fuse passes from the main charge.

When one explosive body is used as a means of firing another, it may be considered that the blow delivered by the gas suddenly formed from the firing charge acts percussively upon the mass to be exploded. The particles of this gas are thrown out with great velocity, but meeting with the resistance of the mass around them, they are checked, and their energy is converted into heat. It is found, however, that the action of explosives on one another cannot be perfectly explained in this way. If the action were simply the conversion of energy into heat, then the most powerful explosive would be the best agent for causing explosion. But this is not the case. Nitro-glycerine is much more powerful than fulminating mercury, but 15 grains of the latter will explode gun-cotton, while 70 times as much nitro-glycerine will not do it.

Chloride of nitrogen is much more violent than fulminating mercury, but larger quantities of the former than of the latter must be used to cause other explosions.

Again, nitro-glycerine is fired with certainty by a small amount of fulminating mercury, while with a much larger amount of gunpowder the explosion is less certain and feebler.

In these cases, it is evident that the fulminating mercury must have some special advantage, since it produces the desired effect more easily than the others. It may be considered that the fulminating mercury sets up a form of motion or vibration, to which the other bodies are sensitive. Just as a vibrating body will induce corresponding vibrations in others, so the peculiar rate of motion or wave of impulse, sent out by fulminating mercury, exerts a greater disturbing influence upon the molecules of certain bodies than that derived from the other substances.*

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* Champion and Pellet have experimented (Comptes Rendus, LXXV., 110, 712) on the "Vibratory Motions Produced by Detonants," and have found that the vibrations excited by different explosions are very different. Thus with a series of sensitive flames corresponding to the scale of g major, 0.03 grm. of iodide of nitrogen at 5 metres distance had no effect, while the same amount of fulminating mercury, affected the flames a, c, e, f, g. At a less distance the iodide of nitrogen influenced the higher notes only, while the fulminate acted on all of them. Nitro-glycerine gave only negative results, due perhaps to the small range of the apparatus.

An explosive molecule is unstable and very susceptible to external influences. Its atoms are in a nicely-balanced equilibrium, which is, however, more readily overturned by one kind of blow than another. The explosive molecule takes up the wave of impulse of the fulminate, but the strain is too great and its own balance is destroyed. So a glass may stand a strong blow, while a particular note or vibration will break it.

In the case mentioned above, of gun-cotton affected by nitro-glycerine or fulminate, the explosion of the nitro-glycerine is strong enough to tear and scatter the gun-cotton, but the blow, though very powerful, is not one that the gun-cotton is sensitive to; on the other hand the fulminate blow, though weaker, readily upsets the molecule of the gun-cotton.

In addition, the explosion proceeds very differently when brought about in this way than when caused by simple inflammation. When a mass of explosive is ignited by a flame, the action extends gradually through it, but if it is exploded by a blow, acting in the manner above described, it is plain that the explosion will be nearly instantaneous throughout, since the impulse will be transmitted through the mass with far greater rapidity than an inflammation proceeding from particle to particle. The explosive reaction will then proceed much more rapidly, and the explosive effect will be much sharper, that is, more violent.

It is found that this difference in explosive effect according to mode of firing is very marked, and it is indicated in the use of the term.

DETONATION.

Detonation is the instantaneous explosion of the whole mass of a body. Thus, when gunpowder is fired in the usual manner true combustion takes place, which goes on with comparative slowness from the surfaces of the grains toward their interiors. On the other hand, when nitro-glycerine is fired by means of fulminating mercury the whole mass explodes simultaneously, or nearly so.

Doubtless, a certain time is always necessary, but with the so-called detonating explosives it can be practically neglected and the explosion called instantaneous.

BODIES SUSCEPTIBLE OF DETONATION.

Some explosives seem to always detonate, no matter how fired, (e. g. chloride of nitrogen, the fulminates, &c.,) while others are detonated or not, according to the mode of firing, (gun-cotton, gunpowder, &c.)*

Probably all explosives can be detonated if the right methods of doing so are known.

Gun-cotton seems to have a greater range of susceptibility to different modes of firing than any other explosive agent. It can be made to burn slowly without explosion, and the rapidity of its action can be increased up to the detonating point. Nitro-glycerine always explodes powerfully, but its effect is much lessened when fired with gunpowder.

Gunpowder, as ordinarily used, is, of course, not detonated, as the violent, sudden effects of detonation would be undesirable. For other purposes (e. g. torpedoes, &c.,) it would be a great advantage if it could be made to give more violent explosive effects by a peculiar mode of firing. It has been demonstrated that this can be done, although the best mode of doing it, or whether detonation is actually accomplished, is not known.† Experiment in this direction can hardly fail to give valuable results.‡

Probably a mechanical mixture, like gunpowder, can never be brought by any mode of firing to approach as near to a perfect detonation as the chemical substance nitro-glycerine or gun-cotton;

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* See page 7.

† The following experiment, devised by Abel, and which the writer has often repeated, illustrates very well the different behavior of gunpowder with the detonating mode of firing—8 small iron cylinders (inch steam pipe, 4–5 inches long, with a cap screwed on one end, answers very well,) open at the top, are bedded in the earth with their mouths level with the surface. In one is placed a charge of fine-grained gunpowder, which is fired with an electric fuse primed with mealed powder. The powder explodes with a dull report, leaving the cylinder in place and uninjured. The second is filled with sand and contains an electric fulminate fuse. On firing this, the cylinder is bulged and cracked a little, but not moved; the third contains the same amount of powder as was put in the first, but is fired with a fulminate fuse similar to that in the second. In this case the report is sharp, the cylinder is torn to pieces, which are scattered about, and the earth in which it is imbedded is thrown out so as to leave a considerable cavity.

‡ Some experiments of this kind have been already made at this Station and they are now being carried on.

but, even if not detonated, better effects for certain uses may be obtained from it if the proper means is used.

Roux and Sarrau have recently published some interesting results of experiments on the different explosive effects produced by some bodies by certain modes of firing.* They divide explosions into two kinds: Detonations or explosions of the first order, and simple explosions, or explosions of the second order. Simple explosions are produced either by direct inflammation or by a small charge of gunpowder. Detonations are obtained from nitro-glycerine, gun-cotton, picric acid, and certain picrates, by exploding with fulminating mercury.

Fulminating mercury, they state, does not detonate gunpowder; but if the exploding charge is a small amount of nitro-glycerine, itself detonated by fulminate, then an explosion of the 1st order is produced. The relative effects were approximately measured by determining the quantities necessary to rupture small cast-iron shells of nearly equal strength.

The following are among the results given, showing the great difference in force of the two kinds of explosion:

	Explosive force.	
	2d order.	1st order.
Gunpowder	1.00	4.34
Gun-cotton	3.00	6.46
Nitro-glycerine	4.80	10.13

MODES OF PRODUCING DETONATION.

Detonation is produced by the application of the requisite concussive force by means of a detonating fuse. A detonating fuse is one which causes explosion by the blow or shock it gives, while the ordinary fuse usually ignites by simple inflammation. Detonating fuses are generally charged with fulminating mercury, a substance which seems to be specially adapted for this use. With such fuses are fired nitro-glycerine and its preparations and dry gun-cotton. Compound detonating fuses are sometimes employed, such as the "primer," for wet gun-cotton, which is a small charge of the dry gun-cotton, fired by fulminate, and the nitro-glycerine fuses of Roux and Sarrau, mentioned above.

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* Comptes Rendus, Oct. 5, 1874.

There seems to be for each explosive about a certain amount and kind of force required to effect detonation, which must not be materially departed from.

If the fuse is too weak, inflammation or a feeble explosion only will result; if too heavily charged, it is more likely to scatter or disintegrate the material acted upon than to explode it.

There is also a relation between the mass of the explosive and the charge of the detonating fuse which must be observed. This relation is more marked with some explosives than with others. Thus, nitro-glycerine is a body easily detonated, and the same amount of fulminate seems to fire equally well all usual quantities. If a single particle is detonated the action quickly extends through the whole mass.

Other substances, less easily detonated, require that as the mass is increased the force applied shall be increased, so that all the particles shall receive a sufficient blow, otherwise only a part will be detonated.

COMPARATIVE VALUE OF DETONATION.

In a detonation we have the fullest *explosive* effect. The suddenness of the explosion concentrates the blow, making it sharp and violent. For certain purposes this is much more effective than would be the same total amount of force more slowly exerted. For instance, in blasting hard rock the violent explosion will throw out and shatter much more rock proportionally than the slower explosion, which intends to escape in the direction of the least resistance. Therefore, in blasting with nitro-glycerine, for example, hard tamping is unnecessary. The explosion is too sudden to allow the gases to blow out the tamping and so escape. The effect is consequently equal in all directions. The advantages gained in blasting with nitro-glycerine and its preparations are so great that their use is constantly increasing, in spite of their high cost and the prejudice against them on account of the many accidents that have occurred with them.

In submarine work, such as torpedo firing, the advantage of the violent explosion is at least equally great.

The slower explosion tends to raise or heave up a large volume of water, spreading and weakening the effect; whereas the detonation is more concentrated, tearing its way through the water. Therefore, unless actual contact of the charge with the object can be obtained, it is advantageous to use a detonating explosive; since its action, although perhaps more local, is much less weakened by the layer of water through which it passes.

In general, when a scattering, tearing effect is desired the detonating explosive must be used.

COMPOSITION OF EXPLOSIVE BODIES.

An explosive body must be composed of constituents which will, on explosion, form large quantities of permanent gas, and they must be so associated that the reaction can be readily brought about, and will proceed with great energy and rapidity. With few exceptions, explosives are essentially composed of carbon, oxygen and nitrogen. On explosion, the carbon and oxygen unite to form carbonic acid gas, and nitrogen is set free in the gaseous state. Carbon and oxygen readily combine, and the combination is attended with a great evolution of heat. The nitrogen plays an important part. In the explosive it is in combination with oxygen, but its attraction for the latter is comparatively feeble, and it readily gives up its oxygen to the carbon, assuming itself the gaseous state. The nitrogen, then, is a means of closely associating together the particles of carbon and oxygen before direct combination takes place, and also increases the quantity of gas formed.

In an ordinary combustion, the oxygen of the air slowly comes into contact with the combustible, but in an explosive the oxygen and carbon are already very near, so that extensive action follows the exciting cause.

Besides these three elements, others are frequently present which act in the same manner, or are necessities of constitution. Thus, in gunpowder, besides carbon there is sulphur, another combustible body, and the nitrogen and oxygen are introduced in the form of saltpetre, (potassium nitrate,) which contains potassium. In many explosives hydrogen enters with the carbon and plays a similar part.

It is convenient to divide explosive agents into explosive compounds and explosive mixtures.

In an explosive compound, the elements composing it are in chemical combination, and cannot be separated except by chemical change.

In an explosive mixture, the ingredients are mechanically mixed and can be separated by mechanical means.

In an explosive mixture, properly so-called, the separate constituents do not have explosive properties, but these belong to the mixture only. For instance, gunpowder is an explosive mixture, but dynamite is not, for it is merely the explosive compound nitro-glycerine, contained in an inert absorbent which has no explosive properties.

While this distinction is a good one in the main, it is not always strictly applicable. There are some mixtures which contain substances having themselves explosive properties. In such a case, however, the explosive properties of the compound are not sufficiently great to render it useful by itself, and it enters into the mixture as a combustible ingredient. Thus, a picrate has a certain quantity of oxygen available in the explosive reaction, but not enough, so it is mixed with a substance supplying oxygen, such as potassium nitrate (saltpetre) or potassium chlorate.

There are a great number of compounds known to possess explosive properties, but only a very few are used in practice. In the following pages there will be taken up under this head nitro-glycerine and its preparations, gun-cotton and its preparations, the picrates, (including, for convenience, some *mixtures* containing picrates,) and the fulminates.

The number of explosive mixtures that have been made is very large, and the number that may be made is almost endless. They are all, however, essentially alike, each containing a combustible substance, and one capable of furnishing oxygen. Some general considerations in regard to them will, therefore, be presented without detail.

EXPLOSIVE COMPOUNDS.

Nitro-glycerine, gun-cotton, the picrates and the fulminates are the only explosive compounds that are practically important. The first three are good examples of the constitution of an explosive. Each is formed from a body composed of carbon, hydrogen and oxygen, by introducing into it a number of atoms of nitrogen and oxygen in feeble combination in place of part of the original hydrogen. In this way a new substance is obtained, unstable from its greater complexity, and also from the peculiar condition of the added atoms. The nitrogen holds the oxygen but feebly, so that a slight disturbance of the equilibrium brings into action the stronger attractions of the carbon and hydrogen for oxygen.

The fulminates are probably similarly constituted, although their mode of formation is not so well understood.

Chloride of nitrogen and iodide of nitrogen have been mentioned in the foregoing pages. They are sensitive substances, exploding with slight provocation, the former with extreme violence. Their properties have been stndied, and they have been occasionally employed for purposes of experiment, but only in very small quantities.

NITRO-GLYCERINE.*

Nitro-glycerine is formed by the action of nitric acid upon glycerine at a low temperature. The process of manufacture consists essentially in the slow mixing of the glycerine with the acid, a low temperature being preserved during the whole operation, and in separating and washing the nitro-glycerine from the excess of acid with water.

Materials. The glycerine is the commercial article of good quality. It must be free from the adulterations often found in it.†

The nitric acid must be strong, having a specific gravity of not less than 1.45. Nitric acid of this strength cannot be obtained in the market, and must therefore be specially prepared for the purpose. This is done by careful distillation from sodium nitrate (Chili saltpetre) and sulphuric acid (oil of vitriol.)*

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* Nitro-glycerine has been made and used at the Torpedo Station for nearly five years, and the statements in the text are entirely derived from experience with it under many and varied conditions.

† The commonest impurity is fatty acid, due to imperfect decomposition of the fat. This is indicated by a precipitate when a solution of a lime salt is added to some of the glycerine mixed with water. A frequent adulteration is dextrin or British gum.

Before it is used the nitric acid is mixed with twice its weight of strong sulphuric acid (oil of vitriol.) The sulphuric acid does not take a direct part in the production of the nitro-glycerine, but takes up the water which is formed during the reaction, thereby preventing the dilution of the nitric acid.

The sulphuric and nitric acids mixed in the proper proportions (one of nitric to two of sulphuric) are placed in a large stoneware receiver, from which the mixture can be drawn as it is required.

Manufacturing Process.

The method used at the Torpedo Station is that of Geo. M. Mowbray, with improved apparatus. The operation may be conveniently divided into two parts:

1st. The conversion of glycerine into nitro-glycerine.

2d. The separation and washing of the nitro-glycerine.

Conversion of Glycerine into Nitro-Glycerine.

The apparatus used for this purpose at the Station is shown on Plate 1. An elevation, section and plan are given, the lettering being the same in the three.

A, A, A, A, A, A, are wooden troughs placed around the brick chimney D, D. In these troughs are the earthen ware pitchers, *a, a, a, a,* .·. *a,* which contain the acid mixture. On the shelf B, above the pitchers, are the bottles, *b, b, b,* . . *b,* which contain the glycerine. The bottles are loosely closed by wooden stoppers with broad rounded tops. Through holes in these stoppers pass loosely the rubber tubes, *c, c, c, c,* which reach to the bottom of the bottles and carry small glass jets at their outer ends. Conical wooden plugs *e, e, e, e,* are placed in the holes through the stoppers alongside the rubber tubes.

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* Another and perhaps a better method is to distill from a mixture of ordinary commercial nitric acid and sulphuric acid in glass retorts. Stronger nitric acid can be thus made, but with more trouble and expense. A still for this purpose has been mounted at the Torpedo Station, but has not yet been much used.

The steam pipe G passes along the shelves B, B, just behind the glycerine bottles.

The air-main F passes under the shelf B, and carries on its under side a number of small short pipes or jets, (two for each pitcher,) to which are attached the rubber tubes, *d*, *d*, *d*, *d*, which hang over the pitchers.

In these rubber tubes are inserted glass tubes, long enough to extend to the bottom of the acid pitchers. In the elevation these tubes are out of the pitchers, but in the section they are in place, as if in use.

The troughs are made tight to hold the ice water with which the pitchers are surrounded. Partitions, with openings at the bottoms, cut off the corners of the troughs forming the clear spaces, *f*, *f*, *f*, *f*. These spaces contain water only, as the partitions keep out the ice. These water spaces are convenient as affording opportunities for quickly emptying a pitcher into water if it becomes necessary. In one corner of each trough is placed a pipe, through which the water may be drawn off into the escape E, when the operation is finished.

The pitchers stand on narrow strips, which raise them off the bottom about two inches, thus giving the cold water free access all about them, and when in position are well under the overhanging hoods, C_1, C_2. These hoods are flat wooden boxes, wide at the bottoms and drawn in at the tops, where they fit against openings in the chimney D, D. In the lower part of the chimney, on the floor below, is placed a grate and fire door (not shown in drawing.)

Each pitcher receives 18 to 20 lbs. of the acid mixture (according to the strength of the latter. All are then set in place in the troughs, covered with glass plates, surrounded with ice and water, and allowed to stand until completely cooled. Into each bottle is put 2 lbs. of glycerine.

When the acid in the pitcherf has fallen to the temperature of the surrounding ice water, the covers are removed from the pitchers, and the air-tubes passed through holes in the hoods down into them. Through these air-tubes a strong current of air is forced by means of a pump driven by steam. This current of air keeps the contents of the pitchers in continual agitation. The air for the pump is drawn through sulphuric acid to render it perfectly dry, and just before it enters the air-main over the troughs it is thoroughly cooled.* The cooling arrangement is made of 10 coils of small tin pipe, which are surrounded by ice (or better, ice and salt.)† These coils are so arranged as to give an extensive cooling surface without impeding the current.

As soon as the air-current has been turned on the flow of glycerine is begun. Each rubber tube *c* is a siphon, which is started by suction through a glass tube inserted in the outer end. As soon as the glycerine runs freely, the suction tube is withdrawn and a fine-pointed glass jet put in its place. The glycerine runs from this jet in a fine stream directly into the pitcher under it. In cold weather the glycerine may become too thick to flow easily. To overcome this the bottles of glycerine are warmed by passing steam through the pipe behind them until the glycerine is sufficiently thin.

The glycerine dropping into the acid mixture is rapidly acted on and converted into nitro-glycerine. The reaction may be indicated by the equation—

$$\underset{\text{Glycerine.}}{C_3H_8O_3} + \underset{\text{nitric acid.}}{3\,HNO_3} = \underset{\text{nitro-glycerine.}}{C_3H_5N_3O_9} + \underset{\text{water.}}{3\,H_2O}$$

The reaction is accompanied by a considerable evolution of heat. This heat must be removed, for if the temperature be allowed to rise too high the glycerine is not converted into nitro-glycerine, but is oxidized or burned, with formation of other substances. The limits of temperature are very narrow. Starting at 32°, the temperature must not be allowed to exceed 48°, and at 50°, 55°, there is great danger of "firing" taking place. The liquid in the pitchers is kept cold by surrounding them with ice-cold water and by the stream of cold air passing into the acid. The most important work of the air current is to keep the acid mixture in constant agitation. In this way the heat generated is quickly diffused through the whole, preventing any sudden local rise of temperature.

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* The pump draws its air from the top of a large tight box; in the bottom of the box is placed a leaden pan containing sulphuric acid (oil of vitriol,) in which is immersed a flat spiral of lead pipe. The inner end of the pipe is closed, and the outer end rises out of the acid and passes through the side of the box into the open air. A great number of small holes are bored in the spiral. As fast as the air is drawn from the upper part of the box the outside air enters through the pipe, bubbling up through the acid. Drying the air is not absolutely necessary, but it is better to do it, as it can be so readily accomplished. Cooling does not entirely remove moisture, and the quantity of air forced through the pitchers is large.

† This is much preferable to allowing the air to come into direct contact with the ice.

The glycerine is much lighter than the acid mixture, and would be apt to collect in little pools above it, and when these were broken up and a quantity of glycerine suddenly brought into contact with the acid, the action would be so rapid that it could not be controlled.

While the glycerine is running into the pitchers, observations with the thermometer are constantly made of the temperature attained in them. If in a pitcher the temperature is found to be rising too rapidly and to be approaching the higher limit, the glycerine is evidently running in too fast, and its flow must be checked, which is done by pressing down the conical wooden plug in the stopper of the glycerine bottle. This plug passes through the same opening as the rubber glycerine tube; therefore, when it is pressed down, it compresses the latter so that less liquid can pass through. If the temperature is too high or continues to rise, the plug is forced hard down, closing the glycerine tube altogether. The flow of glycerine being checked or stopped, the pitcher rapidly cools down again. As soon as the thermometer shows this to be the case, the plug is loosened and the flow again set up. Constant care is therefore necessary, but the operation is a simple one, easily learned and performed by ordinary workmen.

If the limit of temperature is exceeded "firing" takes place, indicated by the copious evolution of red, nitrous fumes, and in extreme cases by flame. Usually when this occurs it is easily controlled by stopping the glycerine stream and stirring vigorously the contents of the pitcher, but if it is violent the pitcher must be emptied into water as quickly as possible.

During the operation of conversion, acid and irritating fumes are given off in large quantities, greatly to the injury of those compelled to breathe them. In the apparatus used at the Station these are entirely removed through the hoods and chimney. A fire in the grate at the bottom of the chimney causes a powerful draught in the hoods, which overhang the pitchers, drawing upwards all the fumes and discharging them into the open air. Generally a small fire at first is sufficient, and often no fire is necessary.

This arrangement for removing the fumes has proved to be of great advantage, not only to the health of the workmen, but also to the operation itself, since they can attend more thoroughly to their work without inconvenience. The hexagonal shape of the apparatus is of course not important, but happened to be convenient for the building in which it is placed and the number of pitchers to be used. In larger establishments the same principle can easily be applied in other ways.

Separation and Washing of the Nitro-Glycerine.

As soon as all the glycerine has been run into the pitchers the conversion is complete, but the nitro-glycerine has to be separated from the large quantity of acid still remaining, This acid is almost entirely sulphuric acid, very nearly all the nitric acid having been used up in the reaction.

The nitro-glycerine is partly in solution and partly suspended in the heavy acid liquid. On diluting the acid with water, the portion in solution is precipitated, and as nitro-glycerine is a much heavier liquid than the diluted acid the whole of it settles to the bottom.

A sketch illustrating the separating and washing apparatus is given on Plate II. The large wooden tub A is sunk in the floor of the converting room. It is filled about three-fourths with water, and has a cover with a square opening, in which is placed a leaden strainer. By means of a rubber hose connected with an air pipe, a current of air is led to the bottom of the tub, vigorously agitating the water in it. The pitchers are taken from the converting apparatus, and their contents poured through the strainer into the tub. The acid liquid descends in fine streams and is quickly diffused through the whole body of water.

When all the pitchers have been emptied the air-pipe is withdrawn, and a short time allowed for settling. The heavy nitro-glycerine collects at the bottom of the tub, so that the lighter acid water may be drawn off from above it. A wooden stop-cock, *b*, is put into the side of the tub, a short distance from the bottom, but above the level of nitro-glycerine. Through this, the supernatant acid liquid is run off and led by a rubber hose into the drain *g*. The tub is placed in an inclined position, and in the lowest part of the bottom is another wooden stop-cock b_2. Through this the nitro-glycerine is drawn in small quantities into the washing-tub B. The washing-tub is of wood, lined with lead, and is supported by trunnions in the wooden frame E. The trunnions are placed just above the middle, so that the tub will stand upright and yet can be easily turned or inverted.

Directly over the washing-tub are the pipes *d* and *e*, provided with valves within the reach of the operator standing by the tub. One is a water pipe and there is attached to it a short piece of hose. The other is connected with the air-main, and has a piece of hose long enough to reach to the bottom of the washing-tub.

A portion of the nitro-glycerine in the large tub A, having been drawn into the tub B, the air-hose is put in and a stream of water turned on. The air-current causes strong ebullition, raising and and spreading the nitro-glycerine through the water. As soon as the tub is full the water is turned off and the air-hose removed. The nitro-glycerine rapidly settles to the bottom of the tub, so that in a few minutes the water above it may be poured off by turning the tub on its trunnions.

This operation is repeated until the nitro-glycerine is thoroughly washed, when it is poured into a copper pail, and a new portion taken from the large tub.*

When the wash water is decanted from B, it falls first into the tub C. As soon as this tub fills, the water runs off through the large lead pipe *f*, which descends nearly to the bottom of *c*, into the tight, open drain *g*. In this tub any nitro-glycerine which may have floated or been accidentally poured off has an opportunity to settle, and is saved.

The building in which nitro-glycerine is made at the Station, is situated close to the shore, and the tight drain, *g*, extends below high-water mark.

When all the nitro-glycerine has been sufficiently washed it is poured into earthen jars, and allowed to stand, covered with water, until it "clears," when it is ready for use.†

The time required for making a run of nitro-glycerine is about five hours, not including the time required for cooling the pitchers, which will of course be different at different seasons. The quantity made in this apparatus, when all the pitchers (24) are in use, is about 80 lbs.

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* Very thorough washing can be obtained by this method. Nitro-glycerine is a heavy, oily liquid, so that any ordinary washing fails to remove the acid contained in it.

The powerful stream of air, however, breaks up the heavy oil into small globules, which are thrown up into the water above, so that there is a good opportunity for the washing action.

† See page 23.

Composition and Properties.

Nitro-glycerine is composed of carbon, hydrogen, nitrogen and oxygen, as indicated by the symbol $C_3 H_5 N_3 O_9$.*

Theoretically, according to the equation on page 19, 1 part of glycerine should give 2.46 parts of nitro-glycerine. In practice we get 1.6 to 1.75 parts. This difference is due partly to losses in operating and partly to the fact that the glycerine used is not anhydrous. Still, under any circumstances the conversion is not perfect. In three experiments on a small scale, made by the writer at the Station, using anhydrous glycerine and the strongest possible nitric acid, the results obtained were 1.96, 1.89, and 2.03 parts of nitro-glycerine to 1 of glycerine used.* Probably other bodies are formed, which are removed in washing.

At ordinary temperatures nitro-glycerine is an oily liquid, having a specific gravity of 1.6. Freshly made it is creamy-white and opaque, but becomes transparent ("clears") and colorless, or nearly so, on standing for a sufficient time depending on the temperature.

It does not mix with and is unaffected by water. It has a sweet, pungent, aromatic taste, and produces a violent headache if placed upon the tongue, or even if allowed to touch the skin at any point. Those constantly using it soon lose their susceptibility to this action.

Freshly made, opaque, nitro-glycerine does not freeze until the temperature is lowered to 3°–5° below 0° Fah., but the transparent or cleared nitro-glycerine freezes at 39°–40° F. Nitro-glycerine freezes to a white crystalline mass. When frozen it can be thawed by placing the vessel containing it in water at a temperature not over 100° Fah.

Pure nitro-glycerine does not spontaneously decompose at any ordinary temperature, but if it contains free acid decomposition is apt to occur. It is, therefore, very important that all acid should be removed by thorough washing when it is made. A number of samples of nitro-glycerine are now in the magazine of the Torpedo Station, which have been kept from two to four years without special precautions, and which are entirely unaltered. No instance has yet been noticed of the spontaneous decomposition of properly made and purified nitro-glycerine. Pure nitro-glycerine is not sensitive to friction or moderate percussion. If placed upon an anvil and struck with a hammer only the particle receiving the blow explodes, scattering the remainder. Nitro-glycerine in a state of decomposition becomes very sensitive, exploding violently when struck, even when unconfined.

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* There are three nitro-glycerines or nitrins, which may be formed by by the action of nitric acid on glycerine. These are $C_3 H_7 (NO_2) O_3$, $C_3 H_6 (NO_2)_2 O_3$, $C_3 H_5 (NO_2)_3 O_3$. The third or trinitnin is the only one which should be formed as is indicated by the equation given on page 19. It is very probable, however, that owing to the use of weak nitric acid, or careless operating, one or both the others are often produced to some extent. If this is true it will go far toward accounting for the various properties that have been assigned by different writers to nitro-glycerine. The writer is studying the products of the reaction in question, hoping to be able to point out the conditions of their formation.

It must be noted that if completely confined the effect may be different, since from its liquid form it is nearly incompressible. In the above case local explosion only occurs, because the hammer is lifted and the rest of the nitro-glycerine is blown away. But if it was so confined that there was no escape for the effect of the explosion of the particle first struck the whole mass would probably be fired.

If flame is applied to freely exposed nitro-glycerine it burns slowly without explosion.

Firing Point.

The firing point is about 180° C. (356° F.) It begins to decompose at a somewhat lower temperature.

Mode of Firing.

Nitro-glycerine is usually fired by means of a fuse containing fulminating mercury. By such a fuse it is detonated, producing a very violent explosion. Fired with a fuse charged with gunpowder its action is very uncertain; sometimes it is exploded and sometimes it is not, but when so exploded its explosive force is much less than when the fulminate is used.*

When frozen, nitro-glycerine cannot be fired, even by large charges of fulminate.†

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* A great many experiments have been made at the Station with gunpowder fuses, but no satisfactory or concordant results have been obtained.

† In one instance 1,600 lbs. of the liquid exploded in a magazine which contained, also, 600 lbs. of the frozen. The latter was broken up and scattered in every direction without firing it.

Storing and Transportation.

Nitro-glycerine may be conveniently kept in large earthen jars, with a layer of water over the explosive. If it is to be transported the liquid form is very inconvenient, especially from the danger of leakage. It is therefore advisable to freeze it and carry it in the frozen state, when it is perfectly safe. For transportation it should be put in strong tin cans holding about 45 or 50 lbs. Each can should be paraffined on the inside, and have, passing vertically through its centre, a tin tube, so that freezing or thawing may be more easily accomplished.

All vessels in which nitro-glycerine has been kept should be destroyed when not wanted for the same use, as the nitro-glycerine cannot be easily washed off.

Use and Relative Force.

Nitro-glycerine is the most powerful explosive in use. In difficult blasting, where very violent effects are required, it surpasses all others. In spite of the many accidents that have occurred with it, it has been found to be so valuable that its use has steadily and largely increased.

Its liquid form is a disadvantage, except under favorable circumstances, as when made at the place where it is to be employed. It, however, forms the essential ingredient in a number of solid mixtures, which will be taken up farther on. When used in blasting or similar work it is usually put in tin cans or cartridge cases.* If the bore holes are tight it may be poured directly in, but it is rarely safe to do this, as there is great danger that some of it will escape through seams in the rock and not be exploded, remaining to cause accident at a future time.

Since nitro-glycerine is so readily detonated it has the advantage of not requiring strong confinement. Even when freely exposed it will exert violent effects, such as breaking masses of rock or blocks of iron. So, in blasting, it requires but little tamping. Loose sand or water is entirely sufficient.

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* A very good case for nitro-glycerine may be made by rolling up stout brown paper into a cylinder of the desired diameter, glueing it, and fastening into one end a cork by choking with fine wire. When dry soak in melted paraffin. The fuse wires should pass snugly through a cork which fits the open end. This cork may be firmly fixed in the case by means of small tacks.

The relative force of nitro-glycerine is not easily estimated, since the effect produced depends greatly on the circumstances. Thus, a charge of nitro-glycerine in wet sand or any soft material will exercise but a slight effect, while the same charge will shatter many tons of the hardest rock. In the former case much more sand would be thrown out by a slower explosion, which would gradually move it, than by the sudden violent shock of the nitro-glycerine, which would only compress the material immediately about it. But in the hard rock the sudden explosion is much more effective than the same amount of force more slowly applied. Roughly, it may be said that nitro-glycerine is eight times as powerful as gunpowder, weight for weight.

Products of Decomposition.

On explosion nitro-glycerine is resolved entirely into the gases—carbonic, anhydride, water, nitrogen, and oxygen, (Nobel) the last-named appearing only in small quantity. If explosion is imperfectly accomplished oxides of nitrogen are formed and the total quantity of gas is lessened. If fully exploded, no disagreeable or poisonous gases are given off.

NITRO-GLYCERINE PREPARATIONS.

The explosive preparations containing nitro-glycerine will be taken up in this place, since they are but forms in which nitro-glycerine itself is presented for use. Their explosive power is derived from the nitro-glycerine in them; so that they are not explosive mixtures in the sense in which that term has been employed in these pages.

In all of them nitro-glycerine is present as nitro-glycerine, but it is mixed with some absorbent substance or vehicle. In this way a solid or semi-solid substance is obtained, which is much more convenient and safer to use than the liquid itself.

DYNAMITE.

In dynamite, the absorbent is usually a natural silicious earth. Deposits of this silicious earth are found in many places, notably in

Hanover. From the Hanover earth the original dynamite was made. This silicious earth or "kieselguhr," is a fine white powder, composed of the skeletons of microscopic animals (infusoria.) It has a high absorptive power, being capable of taking up from two to three times its weight of nitro-glycerine without becoming pasty.

Artificially prepared silica has been proposed by the writer as a substitute for the natural earth, and has been used at this Station with good results. This silica is prepared by precipitating it from a solution of sodium silicate (water-glass) by sulphuric acid, washing and drying. Its absorbent power is a little less than that of the natural earth, but it retains the nitro-glycerine very well.

The process of making dynamite is very simple. The nitro-glycerine is mixed with the dry, fine powder in a leaden vessel with wooden spatulas.

Dynamite has a brown color, and resembles in appearance moist brown sugar. It usually contains from 60 to 75 per cent. of nitro-glycerine. In this country dynamite is made and sold under the name of giant powder.

The explosive properties of dynamite are those of the nitro-glycerine contained in it, as the absorbent is an inert body. It freezes at the same temperature as its nitro-glycerine to a white mass. If solidly frozen it cannot be fired, but if loose and pulverulent, it can be exploded, although with diminished violence. It can be thawed by placing the vessel containing it in hot water.

The keeping qualities of dynamite are those of the nitro-glycerine it is made from. It is safer, because it avoids the liquid condition, and from its softness it will bear blows much better. Exudation must be guarded against. Therefore it must not contain too much nitro-glycerine, especially if it is liable to be exposed to comparatively high temperatures, which tend to make the nitro-glycerine more fluid, and consequently less easily retained.

The firing point of dynamite is the same as its nitro-glycerine. If flame is applied to it, it takes fire and burns with a strong flame, leaving a residue of silica. It is not sensitive to friction or moderate percussion.

Mode of Firing.

Dynamite is fired by a fulminate fuse. Gunpowder will fire it but not with certainty, and the effect obtained is much less than when the stronger agent is employed.

Use and Relative Force.

Dynamite is the best of the nitro-glycerine preparations, and is indeed the best form in which nitro-glycerine can be used. It has earned a good reputation for safety, in spite of the horror usually excited by nitro-glycerine, or anything connected with it. Dynamite will probably be more extensively manufactured and used than any of the other violent explosives. It contains more of the explosive agent than the other nitro-glycerine preparations, and is therefore stronger. Safer than the liquid nitro-glycerine, from its mechanical condition, it is not complicated by the admixture of substances which may exercise injurious effects.

It is used for blasting and other purposes instead of nitro-glycerine. It may be put directly into the bore-holes, but it is generally more convenient to employ it in paper cartridges. It is now extensively employed in mining and quarrying with excellent results, and its use is constantly increasing. Much more effective than powder, it is practically safer, since it is not liable to explosion by sparks or flames. Carelessness is therefore less likely to be followed by accident. For military purposes, also, it is largely employed.

The explosive force of dynamite is, of course, that of the nitro-glycerine contained in it. If it contains 75 per cent. its comparative force may then be approximately stated at six times that of gunpowder.

DYNAMITE NO. 2.

Dynamite proper contains only nitro-glycerine and the silicious absorbent. Mixtures containing other substances are sometimes included under the same name. The true dynamite is often called "Dynamite No. 1," and the others "Dynamite No. 2," or receive fanciful names. All these mixtures contain less nitro-glycerine than the No. 1, so that they cost less per pound, but of course they are proportionately less powerful. Possibly they may sometimes be of use.

The following are varieties of No. 2 dynamite made in England.*

	Per cent.
Nitrate of soda	69.00
Parraffin	07.00
Charcoal or coal dust	04.00
Nitro-glycerine	20.00
	100.00

	Per cent.
Nitrate of potash	71.00
Paraffin	01.00
Charcoal	10.00
Nitro-glycerine	18.00
	100.00

It is hard to see any advantage in these mixtures except that they are cheaper, and might be applied to uses where the great violence of the larger amount of nitro-glycerine is not needed and yet a sharper explosive than powder is wanted. It is improbable that any useful effect is obtained from any other ingredient than the nitro-glycerine. Those containing deliquescent salts (nitrate of soda, for example,) are objectionable from their liability to exudation. All of them will be injured by water, which dissolves the salts, which are the principal ingredients.

It is easy to see that the number of such mixtures that might be made is very great, for almost any dry salt or powder may be taken as an absorbent.† No special value would attach to any of them. The only requisites would be that the absorbents should not exert any injurious action, and that no more nitro-glycerine should be present than could be perfectly retained at the highest temperature that would probably be experienced.

Many of these mixtures have been proposed and made, but it is undesirable at the present time to touch upon more than a few of the most prominent, which will serve as examples.

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* Report of Select Committee of House of Commons on explosive substances, 26th June, 1874.

† During the siege of Paris, in 1870, nitro-glycerine and dynamite were made in the city in considerable quantity for military purposes. The glycerine was obtained from the candle factories, but of course the silicious earth was unattainable. Many experiments were made to discover a good absorbent. Pulverized brick, tripoli, charcoal, magnesia, chalk, lampblack and others were rejected as not possessing sufficient absorptive powers. Finally, the ash of the coal used for gas-making was hit upon. This was a white powder, mainly composed of aluminum silicate, and capable of taking up twice its weight of nitro-glycerine, without becoming plastic. The mixture so made was called dynamite.

LITHOFRACTEUR.

Lithofracteur is a mixture which has the composition (Trauzl)—

Nitro-glycerine	52.10	per cent.
Kieselguhr	30.00	"
Coal	12.00	"
Soda saltpetre	4.00	"
Sulphur	2.00	"
	100.00	"

Sometimes, instead of the sodium nitrate, the potassium or barium salt is used, and variations made in the quantity of nitro-glycerine contained in it. Like all the nitro-glycerine preparations, it has no necessarily definite composition, being merely a mixture made according to the caprice of the manufacturers.*

This preparation is made by Krebs Bros. & Co., in Cologne, and has been used to some extent in Europe. It is claimed by the makers that the other substances (coal, saltpetre and sulphur,) mixed with the nitro-glycerine increase the quantity of gas delivered, and, therefore, the explosive force. This is not, however, correct. Nitro-glycerine is so sudden in its explosion that nothing can be added to it from the slower burning of any of the other combustible ingredients, which are present in comparatively small amount and in bad proportions. Neither does the presence of these substances add anything to the safety of the mixture. They tend to lower its firing point, and render it more easily exploded.

Lithofracteur must be regarded as inferior to dynamite proper, especially for military purposes. It is much more liable to exudation.

The mixtures known in this country as giant powder No. 2, rendrock, &c., and those already spoken of under the head of dynamite No. 2, are somewhat similar to lithofracteur.

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* Experiments with lithofracteur in England by Special Committee, &c. Experiments in 1872 with a lithofracteur containing 66.7 per cent. of nitro-glycerine showed great liability to exudation. In 1873 the manufacturers submitted another sample of 47.5 per cent., which, of course, retained the nitro-glycerine much better.

DUALIN.

Dualin is a mixture made by Carl Dittmar, a Prussian, of nitro-glycerine, sawdust and saltpetre, in about the proportions—

Nitro-glycerine	.50 per cent.	
Fine sawdust	.30 "	
Saltpetre	.20 "	
	100	(Trauzl.)

This preparation is also inferior to dynamite. The sawdust and saltpetre have much less absorptive power than the silicious earth, and retain the nitro-glycerine comparatively feebly. Its firing point is said to be considerably lower than that of dynamite No. 1. Also, its lower specific gravity is a drawback.

GUN-COTTON.

Composition and Formation.

Gun-cotton has the composition indicated by the symbol $C_6H_7(NO_2)_3O_5$, or $C_6H_7N_3O_{11}$, and is formed by the action of concentrated nitric acid on cotton. The reaction consists in the substitution of nitrogen and oxygen in feeble combination for part of the hydrogen in the cotton or cellulose, and is therefore similar to the one by which nitro-glycerine is produced. The equation illustrating the reaction may be thus written:

$$\underset{\text{Cotton or cellulose.}}{C_6H_{10}O_5} + \underset{\text{nitric acid.}}{3\,HNO_3} = \underset{\text{nitro-cellulose or gun-cotton.}}{C_6H_7(NO_2)_3O_5} + \underset{\text{water.}}{3\,H_2O}$$

A number of these substitution products are known, but only one is used as an explosive agent. Some of the others are largely employed for making collodion.

Cotton is the purest form of cellulose, but the latter is the principal part of the ligneous fibre of plants, so that similar products may be obtained from other vegetable fibres.

The process of making gun-cotton consists essentially in exposing the dry cotton for a sufficiently long time to the action of a mixture of the strongest nitric acid with sulphuric acid and in thoroughly washing the gun-cotton thus prepared to remove the excess of acid.

In this reaction also the duty of the sulphuric acid is to take up the water, which is a secondary product.

The fibres of cotton are long flattened tubes, often twisted and knotted. To ensure complete conversion, therefore, considerable time must be allowed for the acid to fully penetrate, and very great pains is necessary to wash out the remaining acid. Thorough washing is, however, difficult. If any acid is left in the gun-cotton spontaneous decomposition may ensue, resulting in explosion.

Gun-cotton has been known for a long time, and many attempts have been made to manufacture and use it, but until recently without success. Accidents, which could only be referred to spontaneous decomposition, cast doubts upon its safety and permanency. The trouble lay in the imperfect purification of the gun-cotton. By the method of Abel a very perfect washing is obtained, and, in addition, the material is prepared in a form convenient to use and yet perfectly safe.

The essential features of Abel's process are the reduction of the wet gun-cotton to a fine pulp, which can be easily washed, and the compression of this pulp into convenient shapes. This product evidently cannot be used for certain purposes for which the fibre is required, such as in gunnery. This is not of importance, as gun-cotton is no longer so applied. For other military applications, such as demolitions, torpedoes, &c., the pulped and compressed gun-cotton is an admirable agent, and is the only form of this explosive now used to any extent.

The following method of preparing long-stapled gun-cotton has, however, been employed at this Station with very good results on the small scale:

Process of Making the Gun-cotton from the Fibre.

Good raw cotton or carded cotton is used. In either case it is treated with a weak solution of sodium carbonate, which removes a small quantity of resin from the raw cotton, or oil from the carded. The purified cotton is washed and carefully dried. The acids are the strongest nitric acid, specially prepared for this purpose, and sulphuric acid, (oil of vitriol.) They are mixed in the proportions of three parts by weight of sulphuric acid to one of the nitric.

A considerable quantity of the acid mixture is placed in a leaden pan and a little dry cotton immersed in it. When thoroughly saturated, the cotton is lifted by an iron fork and placed upon a perforated iron shelf, which hangs in the pans. As much as possible of the acid is removed by pressing. It is then placed in an earthen jar. A quantity of fresh acid, sufficient to replace that removed in the cotton, is then added to the dipping pan and a new portion of cotton put in. When the earthen jar is half full of the dipped cotton, fresh acid is poured into it until the cotton is covered, and it is set away in a cool place for forty-eight hours. The greater part of the conversion takes place during the dipping, but, in order that it should be complete, it is necessary that the cotton should remain in contact with strong acid for a long time.

The gun-cotton is then taken from the jars and passed between a pair of rolls, (covered with rubber, or better, lead,) held together by springs, which are supported in a frame over a trough. Almost all the excess of acid is thus removed.

The gun-cotton is next thrown in a tub of water and vigorously stirred about.

It remains to remove all traces of acid by washing. This is done by passing the gun-cotton through a clothes-wringer a number of times. The clothes-wringer is so mounted that the water pressed out is led away, and the squeezed gun-cotton falls into fresh water.* In this way a more thorough purification is obtained in a short time than by the ordinary method of very long exposure to the action of running water.

ABEL'S PROCESS FOR MANUFACTURING PULPED AND COMPRESSED GUN-COTTON.†

Materials.—Cotton waste is the form of cotton used. It is picked and cleaned, thoroughly dried at 160° F., and allowed to cool.

The acids are the strongest nitric and sulphuric acids, mixed in the proportion of one part of the former to three of the latter by weight. They are mixed in large quantities, and stored in cast-iron receiving tanks.

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* The use of a clothes-wringer for this purpose was suggested to the writer by Mr. Chas. H. Wing, now Professor of Chemistry in the Institute of Technology, Boston, Mass., by whom it had been employed.

† Naval Mission to Europe.—Captain Edward Simpson, U. S. N.—Factory at Waltham Abbey, England.

Treatment with acid.—Cotton in 1 lb. charges is immersed in the acid mixture, which is contained in a trough surrounded with cold water. After a short exposure to the action of the acid, the cotton is taken up, placed upon a perforated shelf, and as much as possible of the acid squeezed out from it. It is then put into jars, covered with fresh acid, and the jars placed in cold water, where they remain for 24 hours.

Removal of acid.—The gun-cotton from the jars is thrown into a centrifugal strainer, which expels from it nearly all of the acid. It is then diffused quickly in small quantities through a large volume of water, and again passed through a centrifugal machine.

Pulping and washing.—Thorough washing is necessary to remove the traces of acid still adhering to the gun-cotton. The washing is expedited and rendered complete by the operation of pulping. The pulping is performed in pulping engines or *beaters*. A *beater* is an oblong tub in which is placed a revolving wheel carrying strips of steel on its circumference. From the bottom, under the wheel, project similar steel strips. By the rotation of the wheel, the gun-cotton suspended in water circulates around the tub, and is drawn between the two sets of steel projections, which reduce it to a pulp. The bottom is movable, so that the space through which the gun-cotton must pass may be contracted as the operation goes on.

When the pulping is complete, the contents are run into the *poachers* for the final washing. A *poacher* is a large oblong wooden tub. At the middle of one side is placed a wooden paddle wheel, which extends half way across the tub. In the poacher the pulp is stirred for a long time with a large quantity of water. The revolution of the wheel keeps up a constant circulation, and care is taken that no deposit occurs in any part of the tub.

Preparation of the Gun-Cotton Pulp for Use.

In the previous operations the cotton has been converted into gun-cotton, and the gun-cotton reduced to a pulp and thoroughly washed. The pulp is next to be separated from the large volume of water in which it is suspended, and compressed into cakes or discs. This is accomplished in two presses. The first press has thirty-six hollow cylinders, in which perforated plungers work upwards. The plungers having been drawn down the cylinders are filled with the mixture of pulp and water, and their tops covered with a weight. The plungers are then forced up by hydraulic power. The pulp is compressed, the water escaping through the perforations in the plungers.

In the second press, the cylindrical masses of gun-cotton from the first press are more highly compressed, a pressure of 6 tons to the inch being applied.

About 6 per cent. of water remains in the cakes, which can be removed by drying.

Properties and Modes of Firing.

The conversion of cotton into gun-cotton causes very little change in its appearance. The latter is somewhat harsher to the touch than the former.

Gun-cotton is insoluble in, and unaffected by water. If flame is applied to dry loose gun-cotton, it flashes up without explosion. Dry compressed gun-cotton burns rapidly but quietly when ignited by a flame. Moist compressed gun-cotton under the same circumstances burns away slowly.

Even if a considerable quantity of gun-cotton is inflamed it will burn away without explosion, but if the quantity is too great, the explosion of a part will be produced. In such cases the outer portion confines the inner sufficiently to cause its explosion.

Dry, unconfined gun-cotton can be violently exploded by a small amount of fulminating mercury. Even in the compressed wet state, gun-cotton can be exploded, but to accomplish this it is necessary to apply the shock from the explosion of a small amount of the dry.

For firing wet compressed gun-cotton, a "primer" is used, which is a cake of the dry, to which is attached a fulminate fuse.

This primer must be enclosed in a waterproof bag or box. It is claimed that complete explosion of large charges of wet gun-cotton can be brought about in this way, but there is some doubt on this point.

The firing point of gun-cotton is about 360° F., (182° C.) Gun-cotton is not sensitive to friction or percussion. Imperfectly converted or badly washed gun-cotton is liable to spontaneous decomposition, which may result in explosion if the conditions are favorable. The pulped and compressed form is free from such danger, for since it can be fired wet there is no need of ever drying it, so it may be kept and used saturated with water.

Storage, Handling and Transportation.

Compressed gun-cotton is stored in the wet state. Care must be taken that it is not exposed to a temperature that will freeze the water in the cakes. If this occurs they are liable to be disintegrated by the expansion of the water in freezing. In cold climates it is therefore advisable to store gun-cotton in pits below the reach of frost.

For convenience in handling, gun-cotton is made into discs of various dimensions, or it may be pressed into slabs or blocks, which may be sawn, drilled, or cut as desired.

The transportation of gun-cotton presents no special difficulties, since there is no danger of leakage, neither is it sensitive to blows.

Use and Relative Force.

As already stated, the use of gun-cotton in gunnery has been given up. The compressed gun-cotton is not adapted to such use, but the violence of its explosion when fired by a detonator makes it of value in torpedoes and military engineering. For these purposes it is largely employed in England. Professor Abel also proposes to use it in shells, and some recent experiments seem to indicate that this may be done to advantage.* A very small charge will break up a shell much more completely than a much larger amount of powder. Experiments were tried with 16-pounder shells, filled with water and fused with an ordinary percussion fuse, to which was attached a small cylinder containing ½ oz. to 1 oz. of dry compressed gun-cotton and the fulminate necessary to detonate it. This arrangement was very successful, the shell breaking up well.

It was concluded: "That shells filled with water and containing a small bursting charge of dry gun-cotton could be safely fired from field guns. That with 1 oz. or ½ oz. bursters of gun-cotton and detonators containing 15 grains of fulminate of mercury the 16-pdr.

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* Committee on Explosives, War Department, England.

common shell filled with water would burst far more effectually than under ordinary circumstances when filled with powder."

Experiments were also tried with 9-in. shell filled with lumps of wet gun-cotton to the amount of 10 or 12 lbs. A dry gun-cotton detonator was used, as in the 16-pdr. shell. This charge burst a shell into an enormous number of pieces.

Very good results were also obtained in practice against targets representing troops.

For blasting purposes gun-cotton has not come into extensive use. It is more troublesome to handle and fire than the more effective dynamite, and has no advantage over them.

The relative force of gun-cotton as compared with gunpowder is variously given from 4-6 to 1. The lower figure is probably nearly right, at any rate for wet gun-cotton.

Products of Decomposition.

On explosion gun-cotton is almost entirely converted into gases, only a trifling residue being left. The gases formed are carbonic acid, carbonic oxide, water, (converted into steam by the heat of the reaction,) nitrogen, and a small amount of marsh gas, (Karolyi.)

The combustion is not so complete as when nitro-glycerine is fired. The latter contains more than oxygen enough to oxidize all its carbon and hydrogen to carbonic acid and water, while the quantity in gun-cotton is insufficient to do this, and a considerable proportion of carbonic oxide is formed. This does not much affect the amount of gas formed, but the heat evolved is considerably less than if the oxidation of the carbon was more complete.

GUN-COTTON PREPARATIONS.

Nitrated Gun-Cotton.—This is made by soaking the compressed gun-cotton in a saturated solution of saltpetre (potassium nitrate) and drying.

Chlorated Gun-Cotton.—This is similarly made, using potassium chlorate instead of nitrate.

Some advantage might be gained by mixing with gun-cotton substances that would furnish oxygen, since, as already stated, it does not contain enough for complete oxidation. The two preparations mentioned might therefore be serviceable. But since it has been discovered that wet gun-cotton can be exploded, this form is used in preference to all others.

THE PICRATES.

General Composition and Properties.

The picrates are salts of picric acid. Picric or trinitrophenic acid is a nitro-substitution product, formed by the action of nitric acid on carbolic acid, (phenol, $C_6 H_6 O$.)

Three substitution products may be derived from this action, but only one, picric acid, possesses any marked explosive properties.

Picric acid has the composition indicated by its symbol—$C_6 H_3 (NO_2)_3 O$, or $C_6 H_3 N_3 O_7$. Picric acid is found in commerce, being used to dye silk and wool yellow. If the acid is heated it takes fire and burns sharply and rapidly, without explosion. The picrates are all exploded with more or less violence by heat or blows. When used as explosive agents they are mixed with potassium nitrate (saltpetre) or potassium chlorate.

A large number of picrates are known, but the potassium and ammonium salts are the only ones that have been much used in explosive preparations.

Potassium Picrate. $C_6 H_2 K N_3 O_7$.

Most violently explosive of the picrates. Potassium picrate and potassium chlorate form a mixture nearly as powerful as nitroglycerine, but it is so sensitive to friction or percussion as to render it practically useless. With potassium nitrate instead of chlorate a less violent mixture is obtained, but one still too liable to accidental explosion.

Ammonium Picrate. $C_6 H_2 (NH_4) N_3 O_7$.

This salt has been proposed by Abel as an ingredient of a powder for bursting charges of shells. The properties of ammonium picrate are very different from those of the potassium salt. If flame is applied to the former it burns quietly, with a strong, smoky flame. If heated, it melts, sublimes, and burns without explosion. It is almost entirely unaffected by blows or friction. This salt, mixed with saltpetre forms Abel's picric powder, (Brugere's powder.) Experiments with this powder in England indicate that it possesses some advantages when used in shells.* A number of shells charged with it were fired from guns of different calibre without accidents. It is more powerful than gunpowder and less violent than nitroglycerine and gun-cotton. It is insensitive to ordinary means of ignition. If flame is applied to it, the particles touched burn, but the combustion does not readily extend to the others. Blows or friction do not explode it. It must be confined in order to develop its explosive force. It does not absorb moisture from the air, so that it may be stored and handled like gunpowder, and is at least equally safe and permanent.

It is prepared for use by the usual gunpowder processes of incorporation—pressing, granulation, &c.; so that it has the same form and may be handled in the same way.

It may therefore be a good substitute for powder when a more violent explosive is wanted and neither gun-cotton or nitro-glycerine are available. It is now being experimented with at this Station, with a view to using it in spar torpedoes. The mixture contains 46 parts of saltpetre and 54 parts of the picrate.

The picrate is prepared from picric acid and ammonia. The picric acid is dissolved in water and ammonia added to neutralization. Another charge of picric acid is then dissolved in the same liquid and ammonia again added. This is repeated several times, and the liquid allowed to stand for some time, when the ammonium picrate crystallizes out in large quantities. The mother liquor is drawn off, the crystalline deposit drained and dried. The mother liquor may be used for the preparation of successive lots of the ammonium salt until it becomes charged with impurities, when it may be otherwise treated or thrown away. In this way a considerable amount of the salt can be expeditiously prepared with little labor and without much loss. The working of the mixture is, of course, to be done at a powder-mill.

At the time of writing a quantity of the picrate has just been made at the Station, and is to be sent to a powder factory. Small quantities of the mixture have been experimented upon with favorable results, but of course only in the state of fine powder.* In this condition it explodes with greater force than gunpowder and is less sensitive to the ordinary methods of firing. If flame is applied to it the portion affected burns and snaps, but the combustion does not become general.

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* Investigations and Applications of Explosive Agents. F. A. Abel.

THE FULMINATES.

The fulminates are salts of fulminic acid, ($C_2 H_2 N_2 O_2$). The mercury salt is the only one of practical value. All of them are easily exploded, and some are excessively sensitive. Their explosions are very sharp from the extreme rapidity of their decomposition, but from the small amount of gas given off, the force exercised is not very great. The explosive effect obtained is of a local character.

Composition and Formation.

Fulminating mercury has the composition indicated by the symbol $C_2 Hg N_2 O_2$. It is formed by the action of mercuric nitrate and nitric acid upon alcohol. The best mode of preparing it is as follows:

Dissolve 1 part of mercury in 12 parts of nitric acid, sp. gr. 1.3, and pour this solution into 11 parts of alcohol, 85 per ct.† Place the vessel containing the mixture in hot water until it darkens and becomes turbid and begins to evolve dense white fumes. It is then removed from the water. The reaction goes on, with strong effervescence and copious evolution of dense white ethereal vapors. If red fumes appear, cold alcohol should be added to check the violence of the action. The operation should be performed at a distance from a fire or flame and in a strong draught, so that the vapors will be carried away.

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*February 16, 1875. A 24-pdr. shell, containing 15 oz. of the mixture and an ordinary service igniter, (primed with rifle powder,) was burst into a large number of fragments, which were thrown to great distances.

† A number of methods are given by various authors, but this is the best Theoretically, 1 part of mercury should yield 1.42 parts of fulminate, but in practice a less amount is produced. By the above method the writer has obtained 1.18 and 1.24 to 1, a better result than by any of the others. Some of the mercury passes off in the vapors and a little remains in the liquid. With these proportions there is little tendency to decomposition of the fulminate with re.formation of metallic mercury.

When the liquid clears and the dense white fumes are no longer given off further action is stopped by filling up with cold water.

The fulminate settles to the bottom of the vessel as a gray crystalline precipitate. The supernatant liquid is then poured off, and the fulminate washed several times by decantation or upon a filter.

Properties and Uses.

Dry fulminating mercury explodes violently when forcibly struck, when heated to 186° C., (367° F.,) when touched with strong sulphuric acid or nitric acid, by sparks from flint and steel or the electric spark.

When wet it is inexplosive. It is therefore always kept wet, and dried in small amounts when wanted for use.

Its explosive force is not much greater than that of gunpowder, but it is much more sudden in its action.

The readiness with which it may be fired makes it an excellent means of causing the explosion of other substances, and it is for this purpose only that it is used. It finds many applications, either pure or mixed with other bodies—in percussion powder, percussion caps, primers, fuses, detonators, etc., etc. It presents many advantages for this use. It is of special importance for the peculiar power it possesses of causing the violent explosions called detonations. (See page 12.) It is, therefore, a requisite for exploding nitro-glycerine, gun-cotton, and their preparations.

Detonators or detonating fuses are charged with pure fulminating mercury—15 to 25 grains in each. Fifteen grains is sufficient for nitro-glycerine or its preparations; 25 grains is used with compressed gun-cotton. In detonating fuses the fulminate should be contained in a copper cap or case, and must not be loose. Charging should be done with wet fulminate, as it is very dangerous to handle it when dry.

Properly made fulminate fuses are perfectly safe, but unless care is taken in making them they may be dangerous.

EXPLOSIVE MIXTURES.

As has been already remarked, an explosive mixture has two essential ingredients. One is a substance which is readily combustible, and the other, one containing a large amount of oxygen, which it will easily give up. The combustible substance in almost all cases is carbon, with which is usually associated hydrogen. Occasionally other oxidizable bodies, such as sulphur, are also used, but carbon is the most important element. It is largely employed in the form of charcoal, which is nearly pure carbon, but evidently any organic substance containing it in large proportion will serve nearly as well. In all cases the action is the same. The carbon is oxidized to carbonic acid gas and the hydrogen to water, with great evolution of heat. The number of combustible substances that may be used in this way is very great, but all of them play the same part in the mixtures.

The substance in an explosive mixture which is to supply the oxygen must be one containing that element in large amount, in such a condition that it can easily be released, and it must be one which will not act directly on the other substance or substances present.

The nitrates and chlorates are powerful oxidizing agents and are almost invariably used in explosive mixtures. There is a great difference in the readiness with which these two kinds of salts give up their oxygen, and, consequently, they form different classes of explosive mixtures. We may, therefore, divide the usual explosive mixtures into two divisions:

1st. Those containing nitrates; and
2d. Those containing chlorates.

1*st.*—*The Nitrate Class.*

In the nitrates the oxygen is held with considerable force, so that a strong external influence is required to separate it. In general, then, the mixtures made from the nitrates are not very easily exploded, and their action is, comparatively speaking, moderate. Compared with those of the second class, they are not sensitive to friction or percussion. Any of the nitrates may be used in explosive mixtures, but, practically, potassium nitrate (saltpetre) is the only one employed to any extent. With sulphur and charcoal, it makes up the numerous compositions, of which gunpowder is the most important. Occasionally sodium nitrate (Chili saltpetre) is used instead of the potassium salt, but its tendency to deliquesce makes it much inferior. Gunpowder may be considered as the representative of the nitrate class, and its well-known explosive properties may be taken as those of all belonging to the class.

Picric powder (already described) belongs to this class. Sawdust powder, or Schultze's white gunpowder, contains saltpetre. It is made by converting purified sawdust into a nitro-cellulose, (resembling gun-cotton,) and mixing this with the nitrate. It is said to work well in small arms.

2d.—*The Chlorate Class.*

Chlorate mixtures are very sensitive to friction and percussion, and they explode with great sharpness.

The potassium salt is the only one of the chlorates which is employed in these mixtures. Very many chlorate mixtures have been made, but none of them are of much value. Of many of them it may be said that they are so liable to accidental explosion that they are unfit for use.

The following are examples of chlorate mixtures:

Potassium chlorate with rosin.
Potassium chlorate with galls, (Horsley's powder.)
Potassium chlorate with gambier, (Oriental powder.)
Potassium chlorate with sugar, (used in "chemical" fuses.)
Potassium chlorate with potassium ferrocyanide, (White or German gunpowder.)
Potassium chlorate with tannin, (Erhardt's powder.)
Potassium chlorate with sulphur, (Pertuiset powder, used in explosive bullets.)

Potassium chlorate is the basis of many fuse mixtures, some of which are used to a certain extent.

Sprengel has published some interesting and important statements in regard to certain new classes of explosive mixtures.* He finds that a variety of organic substances dissolved in nitric acid of 1.5 sp. gr. explode by detonation. Nitro-benzol mixed with nitric acid in proper proportions gives a mixture which explodes with intense violence, if fired by a detonating fuse. Absorbed in silicious earth, it burns slowly when flame is applied, and is less sensitive to blows than dynamite or gun-cotton. Picric acid dissolves in nitric acid, forming a similar mixture. Many other combustibles may be thus used but these mixtures are inconvenient to handle, since they contain concentrated nitric acid. Still their power and cheapness are so great that they may be of value. He points out a new mode of preparing potassium chlorate mixtures, which avoids the dangers and difficulties usually connected with them. Mixing potassium chlorate with solid combustible substances is an extremely dangerous operation, and the mixture so made is very sensitive. He uses instead combustible *liquids*, absorbing them in porous cakes or lumps of potassium chlorate, which can be done without risk. These mixtures are not exploded by fulminate, unless a certain amount of sulphur or nitro-compound is present. For example, carbon disulphide and nitro-benzine give mixtures that in blasting granite proved to be four times as effective as gunpowder. But by increasing the power of the detonator a mixture of the chlorate with a hydrocarbon (benzine, petroleum, phenol) could be satisfactorily fired. This was done by surrounding the detonator with an envelope of gun-cotton. These results are of great importance. They indicate methods of making explosive agents that will compare very favorably with those now in use, in cheapness, power, and safety. The readiness and simplicity with which they may be prepared makes it possible to keep separate the ingredients until the mixture is required for use. This has been attempted, but is impracticable when two solids are used, but much easier with two liquids or a solid and a liquid.

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*Journal of Chem. Soc., Vol. XI, 796.

EXPLOSIVE AGENTS IN TORPEDOES.

In discussing at this time some applications of explosives to torpedo purposes, only the three explosive agents, gunpowder, gun-cotton, and nitro-glycerine, need be considered. They are the only ones that are, or that probably will be, extensively used. The liquid condition of nitro-glycerine is inconvenient, and therefore this material will be employed in some of its solid preparations. Of these, as already stated, dynamite is by far the best, and will fairly represent all of them. Gun-cotton is best used in the wet, compressed state. In these notes, therefore, wet gun-cotton and dynamite will be taken as the forms of these agents which will be applied in torpedoes.

Comparison for use in Torpedoes.

Gunpowder, gun-cotton, and dynamite, may be compared as to their properties and their explosive effects.

Gunpowder is a familiar material, in extensive use for military and other purposes. It can be transported and handled with ease and safety. It can be fired by ordinary and simple methods. It has, however, the great disadvantage for submarine work, that it is very easily injured by water, so that tight cases for containing it are absolutely necessary.

Gun-cotton compares very favorably with gunpowder in the safety of its manufacture, and its freedom from liability to accident. It is unaffected by water, and may be kept and used when saturated with water. In this state, however, it is liable to be injured by cold, (see page 36.) It is more costly and not readily obtained, for since it is not otherwise applied it must be specially prepared. In addition, it must be fired in a peculiar and rather complicated manner.

Dynamite is already widely employed for blasting purposes. Its manufacture can be readily carried on, involving less elaborate apparatus than is necessary for the other two agents under consideration. It contains, however, nitro-glycerine, a body which has an evil reputation. In many respects this reputation is undeserved, still there is much yet to be learned about nitro-glycerine, and until our knowledge of it has become more nearly complete, some uncertainty must attach to it and its preparations. Nevertheless, dynamite has earned for itself, in spite of many obstacles, a good name, and has proved to be a valuable explosive. It is not directly ffected by water, but if diffused through water its firing is hindered and exudation may occur. Its high freezing point is a disadvantage, although if loose it can be fired when frozen, but probably with lessened violence. It must be fired by a special fuse, though this is simpler than the one required for gun-cotton.

Both dynamite and gun-cotton are much more powerful than gunpowder.

In regard to explosive effects, there is a marked difference between gunpowder and the other two. In the explosion of gunpowder the effect is produced by the comparatively slow formation of gas; and is therefore of an accelerating character. Of course the action is very rapid, otherwise explosive effect would not be obtained, but is slow enough to cause an uplifting or heaving rather than a shattering or rending effect. This may be changed to a certain extent, by a peculiar mode of firing, (see page 35,) but holds good under the usual conditions.

With dynamite and gun-cotton sudden or detonating explosions are produced. In such case the action is intenser and a more concentrated blow is delivered than with a slower explosion. The result is a violent shock, causing a tearing and shattering effect. In submarine explosions this difference is very important. In torpedo defense it will rarely happen that actual contact of the charge with the object can be brought about. A cushion of water must intervene, through which the explosion must be effective. Through water the slower gunpowder explosion is much less effective than the sharper one of a detonating material. By the one the water is lifted or moved in rapidly increasing quantity, so that in a very short space the effect is very greatly diffused and diminished; by the other a nearly equal effect will be obtained within the sphere of action. The radius of this sphere may be proportionally smaller, but the diminution along it is less. At the best explosive force diminishes very rapidly by transmission through water, but within limits the loss is less with the violent explosives. Under water a shattering effect is wanted, not a propulsive.

Further, with powder it is necessary that the object should be in the line of least resistance; for, since the force exerted is a slowly gathered one, it will be turned in that direction. With the others, since confinement is not requisite, a nearly equal effect is exerted in every direction; so that it is only required that the object should be within the effective distance of the charge. Also, in most cases, effective charges of gunpowder must be inconveniently large.

Gunpowder will be used in torpedoes to some extent from necessity or from motives of convenience, but when they can be obtained the more powerful explosives will have the preference. Of the others, gun-cotton has the great advantage that great confidence may be felt in its safety; so that it may be carried and handled in large quantities, and it will be preferred when it can be obtained. In

England it is made at the Government Powder Works at Waltham Abbey and stored in large amounts for use. But in most countries it is doubtful if gun-cotton factories will be built in order to provide a material for use in torpedoes only. Recourse will be had to an agent more extensively applied in other ways, and which can be obtained when needed from private manufacturers. Dynamite then, on the whole, may be considered as the explosive agent best adapted for torpedoes. Besides the greater readiness with which it can be made or purchased, it has other advantages over gun-cotton. It is more readily fired, not requiring the special arrangement necessary for gun-cotton. It is more easily handled and is less injured by cold, since if frozen it can be restored to good condition by thawing. With greater experience with dynamite it is probable that the doubt in regard to its safety will be removed and that it may be used under ordinary circumstances without danger.

Dynamite will be used in all forms of torpedoes; in ship and boat torpedoes, as well as in permanent mines for harbor defense. There is, of course, some objection to taking dynamite on shipboard, but if torpedoes are to be of any use in war it will become a necessity to do so, and it will be done without hesitation. Gun-cotton will certainly be so carried, but where this body is not to be obtained, dynamite will be used instead. Further, offensive torpedoes will be operated for the most part from vessels specially designed for such work, and there can be no objection to supplying them with the most effective material.

Gunpowder is more likely to be used in torpedoes directly operated from ships or boats (spar and towing torpedoes) than in any others. In fact, since with these actual contact is obtained, it may serve tolerably well. Yet, in actual service there are strong reasons for the employment of the more destructive agent. Take the case of the spar torpedo. The charge of powder is bulky and heavy, requiring a large and strong case, spar and tackle. There is always danger of leakage of the case. Great advantage would result if a small charge of dynamite in a light bag or box was used, which would be more effective. This could be operated by a simple apparatus less liable to injury or accident. Especially does this apply to boat or launch torpedoes. A light rod or bar, sufficient for carrying the small charge would seem to be as efficacious as the most elaborate arrangement, and much more to be depended upon in action, since it could be easily and rapidly operated and readily replaced if injured. In night attacks it is of the last importance that the simplest possible arrangement should be employed. An attempt to blow up a vessel from a launch is a hazardous undertaking, and the means provided should be of the most effective character.

It has been shown that charges of gun-cotton or dynamite, as powerful if not more powerful than those now used of powder may be safely fired from a boat's spar.*

Spar and towing torpedoes do not carry large charges, so that it is better that a powerful agent should be employed in them.

It is very desirable, therefore, that it should be known what can be done with dynamite, so that it can be used in case of necessity. Fuller information is needed as to its keeping qualities when exposed to changes of temperature and other conditions.†

It is worthy of elaborate experiment, since it promises to be largely employed in torpedoes.

Modes of Using and Firing.

When gunpowder is used in torpedoes care must be taken that the cases are water-tight, and they must be strong enough to give the confinement necessary to burn all the charges. Injury from leakage may be avoided by placing the charge in a light, tight inner case, which fits snugly in the strong outer case. This inner case may be made of tin, copper, zinc, or wood, well pitched over, or, as suggested by Captain Harding Steward, of vulcanized india-rubber.‡

The strength of case required will depend somewhat upon the mode of firing. The more rapidly the ignition goes on the less the confinement that is necessary. The usual mode of firing gunpowder is by application of flame. To insure rapid ignition, several fuses may be distributed through the charge, to be fired simultaneously. A better mode is to use a single fuse, heavily primed, and place this in a strong cylinder which passes through the centre of the charge, and which is pierced with a number of holes. The cylinder must be covered with paper or fine wire gauze, to keep the powder from entering it. (See note, page 9.) On firing the flame from the fuze passes through the holes and ignites the charge from a number of points simultaneously. This arrangement is a very effective one. Still, with the ordinary mode of ignition, however complete, a certain amount of confinement is required. It is probable that by a special mode of firing, gunpowder may be made to explode more suddenly, but this has not yet been put into practice. (See page 10.)

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* Torpedo Station.

† This might be tried by sending small quantities on board a cruising ship and carefully observing any changes that might take place. The Danish Government have tried experiments of this sort for several years past with very satisfactory results.

‡ Notes on Torpedoes, Major Stotherd, R. E. (This has been tested for lining powder-barrels, and resulted in failure.—W. N. J.)

Gun-cotton is usually prepared in discs of various sizes. This shape, however, stows badly, for it is very desirable that a charge to be exploded by a concussive blow should be as solid as possible. In the Oberon experiments discs 3 inches in diameter by 2 inches high have been used, but it is now proposed to make solid masses or slabs of gun-cotton, which can be closely packed in the case. As it is wet itself an absolutely tight case is not required to contain it, and as it is supposed to be detonated strong confinement is not needed to develop its explosive force.

Dry gun-cotton is violently exploded by a fuse containing 15-25 grains of fulminating mercury. Wet gun-cotton cannot be so fired, but is exploded by the blow from the detonation of some of the dry. The fuse or "primer," as it is called, for wet gun-cotton, consists of a small amount (say ½ lb. to 1 lb. for large charges,) of dry gun-cotton, to which is firmly attached a detonating fuse. This primer must be carefully protected from moisture, and is, therefore, placed in a waterproof bag or case. The correct relation between the size of the primer and weight of charge is not fixed. In the sixth Oberon experiment a 2-lb. primer was substituted for the 1 lb. previously used, and it was thought that increased effect was obtained. It is not improbable that the fullest possible effect is not obtained from wet gun-cotton by this mode of firing, and that further experiment will develop some better method.

Dynamite is a soft pulverulent substance, which can be easily handled and put into vessels of any shape. It is fired by a fuse primed with fulminating mercury (15 to 20 grains.) As it is always detonated it does not require confinement, nor is it injured by moisture. In using it care must be taken that no exudation takes place.

Sizes of Charges and Effects Obtained.

The sizes of torpedo charges depend upon the circumstances of use. Since destructive effect is desired, as large a charge as the circumstances will admit of will be employed.

In spar torpedoes 50 to 100 lbs. of gunpowder are the usual limits. 50 lbs. is too small for general purposes; 150 lbs. and the case necessary to contain that amount make a heavy and cumbrous torpedo, inconvenient to work and requiring very stout apparatus. Also an unusually long spar must be employed. A charge of 100–120 lbs. is about right. This charge is most effective when submerged about 10 feet.

Gun-cotton and dynamite have not been much used in this way. Probably charges of 20–30 lbs. of either could be easily applied, with much better effect than 100 lbs. of powder. A few experiments would quickly decide the matter.

Harvey's towing torpedoes are made of two sizes; the large one will contain 76 lbs. of rifle powder, and the small one 27 lbs., or of gun-cotton 60 and 22 lbs., and of dynamite 100 and 35 lbs. respectively.

Automatic torpedoes can, of course, carry charges according to the wish of the builder. These torpedoes are costly and require special means of handling. Therefore, they should be made as effective as possible. Only a violent explosive will be used in them. A charge of 100 lbs. is as small as should be allowed.

The Fish or Whitehead has been made to carry charges of 40–60 lbs. of gun-cotton.

The larger automatic torpedoes, like Lay's and Ericsson's, carry heavy charges. The Lay torpedo, now at the Station, is intended for 500 lbs. of explosive. The Ericsson torpedo that has been experimented with had an allowance of 350 lbs. for charge. These amounts would seem to be ample, although these torpedoes can easily be constructed to carry much heavier charges if desirable. It can hardly be doubted, however, that 350–500 lbs. of dynamite exploded in contact with a vessel would destroy her.

Torpedoes for harbor defense or permanent mines may be considered as weapons constructed at leisure, and upon calculations of the work required and the circumstances under which it is to be done. The sizes of the charges used in them will be regulated by many conditions, such as whether the torpedoes are buoyant or rest upon the bottom, the depth of water, the effective horizontal distance, relation to other charges, position in the system of defence, etc., etc., etc. For example, electrical torpedoes will usually be placed upon the bottom with their circuit closers above them, and must, of course, be more heavily charged than torpedoes which come in direct contact with the vessel. Again, isolated torpedoes may have very large charges, but where groups or lines of torpedoes are laid down, the charges will depend upon the mode of arrangement and the distances allowed.

The construction of the system will depend upon local conditions and the charges will be arranged to suit it within certain limits.

Many sizes of charges will therefore be employed in permanent mines. Of gun-cotton or dynamite 100 lbs. will be small; 200 to 300 moderate; 300 to 500 often used, and not unfrequently 500 to 1,000, and occasionally even more. Not less than 500 lbs. of gunpowder should be used for a charge, and larger amounts in many cases. Extensive experiments with large charges must be made before definite rules can be laid down for the sizes of charges.

Torpedo warfare is as yet very largely theoretical. Systems of defence have been designed, various forms of movable torpedoes invented and experimented with, but they all lack the crucial test of actual service. No part of the subject is less known than that which involves the explosive effect obtainable, and the manner and extent of its transmission. Very much has been done mechanically and electrically in making and experimenting with all kinds of torpedo constructions, fuses, cables, &c., so that these points have attained a great development, but the matter of actual effectiveness has been much neglected.

Perhaps this has been done on the principle that charges large enough and to spare could always be used.

Still, the difficulty is left of placing these charges near enough to cover completely the space to be defended and yet having them so far apart that the explosion of one will not explode others or injure their attachments. It is, then, necessary to know the exact effect that can be obtained under varying circumstances of depth and horizontal distance.

The question of depth is of more importance with powder than with the violent explosives, since the effect of the powder explosion is turned in the direction of the least resistance. If the charge is too near the surface the force escapes upwards and the lateral effect is greatly diminished. At the surface the effect would then be small. If too deeply submerged, the quantity of water to be moved becomes too great and the lateral action is greatly lessened. Charges of powder must then be largely increased with depth.

Stotherd assumes 500 lbs. of powder at 20 ft. depth and 2,000 lbs. at 40 ft., and considers that an approximation to the amounts required between these depths may be obtained by taking the squares of the depths as the charges required and allowing one-fourth additional if the torpedoes are buoyant or rest on soft bottom.*

With the detonating explosives, the explosive blow is equal in every direction. Submersion is not necessary to direct the force. A charge of gun-cotton or dynamite, if detonated in contact with an object, will be practically as effective if on the surface as if 10 ft. below. When water intervenes, the effective horizontal distance or radius of explosive effect must be known. This will be affected by depth. At the greater depth the transmission of the explosive blow takes place through water at increased pressure, lessening the lateral effect in a larger proportion.

Stotherd, by experiments with known charges at different depths, finds that when a charge is fired at its most effective depth the radius of explosive effect may be derived from the equation

$$R = \sqrt[3]{8c.}$$

in which R = radius of explosive effect in feet and c the charge of gunpowder in lbs.† For gun-cotton, fired with an ordinary fuse, this equation becomes

$$R = \sqrt[3]{32c.}$$

(Gun-cotton is considered to be four times as powerful as gunpowder.)

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* Notes on Torpedoes, Chap. 3.

† Notes on Torpedoes. Loc. cit.

This determination, if considered to be approximately correct, indicates very short effective distances, and later experiments have certainly demonstrated that such is the case. Much experiment is yet needed in this direction.

Daudenart gives as deductions from recent experiments that the explosion of a buoyant torpedo, charged with 500 lbs. of powder, at a depth of 32 ft., will not injure other torpedoes 32 ft. distant horizontally; that 200 lb. and 100 lb. charges at 22 ft. and 16 ft. depth will have no injurious effect on others at horizontal distances of 22 ft. and 16 ft. respectively.* These distances probably apply only to the safety from explosion of the contiguous charges.

Stotherd considers that a distance between torpedoes of six times the radius of explosive effect is a safe one.

It must be remembered that an interval must be allowed between torpedoes of a line great enough to prevent possible damage from the explosion of one to the circuit-closers, moorings, cables, &c., of its neighbors, as well as to guard against their explosion by concussion. Also, the chances of explosion of gun-cotton or dynamite by concussion are greater than if powder is used.

An interesting series of experiments has been going on in England bearing upon this subject, and although unfinished, it has presented some valuable results. These experiments have been quite fully noticed by the technical journals as they have been performed, but it may not be amiss to bring them together at this time.

The object against which the explosions have been directed is an old iron paddle-steamer—the Oberon—to which has been given a double iron bottom, similar to that of the iron-clad Hercules. The Oberon, of course, does not fully represent the Hercules, as it is a much weaker and lighter vessel. In the Oberon's central compartment was placed a surface condenser. This condenser was placed upon the bottom, without fastening or bed, resting on one side against some heavy iron water tanks, and on the other supported by two timber struts, and was fitted with inlet and outlet valves open, and with the Kingston valve of the feed pump closed.

The weight of the Oberon's hull, before the outer skin and frames were added to represent the Hercules double bottom, was 590 tons. Weight after that addition 926 tons. Weight of condenser, slinging cables to hull, &c., 30 tons.

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* **La Guerre Sous-Marine, 1872.**

The Oberon's draught was 11 feet 3 inches mean.

The attacks were made against the starboard side of the vessel, and in this side were fitted forty-four crusher gauges, while over each side were suspended by ropes 18-pounder round shot, each shot carrying a crusher gauge.*

The first explosion took place August 4th, 1874, in Stokes Bay, near Portsmouth. The torpedo was a service mine case—wrought iron cylinder, with rounded convex ends—containing a charge of 500 lbs. of wet, compressed gun-cotton in 9 oz. discs. The priming charge was 1 lb. of dry gun-cotton in a water-proof bag. The firing was accomplished by two detonating fuses, in divided circuit, and the firing wire was led to the shore, about 800 yards distant. The torpedo was placed upon the bottom, at a distance of 100 feet, horizontally from the Oberon, and with 48 feet of water over it. On explosion a large column of water and mud was thrown up, the Oberon was lifted up and considerably shaken. The only damage done was the splitting of the inlet pipe of the condenser, causing a leak. If the condenser had been firmly set very probably this would not have occurred.

The hull was not harmed. Two lambs which had been placed on board were found unhurt.

The second experiment was made August 21st. All the arrangements were the same as in the first attempt, except that the Oberon was 80 feet horizontally from the torpedo and that the latter had 52 feet of water over it. The Oberon was much shaken by the explosion, and everything that was loose thrown out of place, but no serious effect was produced.

The third experiment was made September 5th, with the same circumstances, except that the horizontal distance between the torpedo and the Oberon was reduced to 60 feet. The usual column of water (about 200 feet in height, 150 feet diameter at the base) was thrown up and the Oberon heeled over noticeably to the blow. The shock borne by the vessel was a heavy one, some loose pieces of timber that had been left on deck were thrown up into the air, water tank covers unlocked and thrown off, and the timber struts which supported the condenser were broken. The sheep and rabbits on board were not harmed. On examination it was found that the hull had received no actual injury, but from the appearance of the outer plating, it was thought that the torpedo had been almost near enough to be effective.

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* The port side was reserved for trials with Harvey, Whitehead, and boat torpedoes.

The fourth attack was made September 26th, 1874. The torpedo was placed 50 ft. horizontally from the Oberon, lessening the space between them by 10 ft. instead of 20 ft., as in the preceding cases. It was supposed that at this distance considerable effect would be produced, and great precautions were taken to insure the floating of the vessel until it could be docked and examined. Her iron ballast was removed and its place supplied by water casks and closed iron tanks containing sufficient water to bring her down to the required draught. An old sail was fastened to the bulwarks by one side, the opposite side was weighted and the whole rolled up and lightly lashed, so that it could be readily dropped to partially cover an opening in the bottom if one was made by the explosion. The outer edge of the column of water struck under the Oberon's side, so that she was lifted up several feet, falling into the disturbed water. She, however, floated perfectly well, only the water which fell on deck being found in her.

On examination of her bottom in dock it was perceived that considerable damage had been done. The outer plating between the frames of the double bottom was driven in, forming a series of flat arches, and a number of the bracket frames buckled up, but the inner skin was not affected. The outlet pipe of the condenser was split between the skins of the double bottom, a number of rivets started, and all the flanges of the condenser's sea connections damaged. The total injury, however, was not great, as the Oberon floated perfectly well.

For the fifth explosion, November 9th, the torpedo, charged as before, was suspended from a spar projecting 30 ft. from the ship's side and was submerged 48 ft., (66 ft. of water,) thus bringing it 52 ft. from the hull. The firing of the torpedo was not accomplished, only the priming charge being exploded. This was accounted for by supposing that there was not sufficient contact between the primer and the main body, or that the primer was not sufficiently strong, although it exerted force enough to burst the iron torpedo-case.

For the sixth experiment, November 11th, the primer was increased from 1 lb. to 2 lbs. of dry gun-cotton, all the other conditions being the same as in the previous attempt. The explosion seemed to be more violent than in any of the other cases, a very large volume of water being thrown up. Immediately after the explosion the pumps were tried, but it was found that no leaks had been caused. On docking it was observed that some damage, not of a material character, had been done to the outer skin, while the inner was unhurt. The torpedo was placed well in front of the starboard bow, so that all its influence was exerted against the forward compartments, and all the movable objects in them were displaced. The general effect was not as great as in the earlier explosions, due perhaps to the fact that in this case the torpedo was buoyant.

In the seventh experiment, November 28th, all the details were the same as in the sixth, except that the torpedo was placed upon the bottom. By this explosion more injury was affected, and this was confined to a smaller area. The ground torpedo, therefore, struck a more concentrated and effective blow than the buoyant mine. As before, the outer skin only was damaged.*

Although considerable damage was done, the Oberon was not seriously injured by any of these experiments. It may be said that the results would have been different if the Oberon had had the 9,000 tons of inertia of the Hercules, instead of the 1,000 tons she really had. On the other hand, the Oberon was structurally very much weaker than the Hercules, and less able to resist the blow she received. Very possibly, also, an iron-clad, fully equipped, meeting with such a shock, might be disabled by some injury done to her boilers or engines. The experiments against the Oberon do not settle these points, but they do show that at a moderate distance 500 lbs. of gun-cotton is practically harmless against the hull of an ordinary iron-clad.

To produce destruction such a torpedo must be considerably nearer than 50 ft., and it is probably safe to say that at 100 ft. distance the explosion would not exercise any injurious effect.

These remarkable results are of great importance, as demonstrating the narrow limits of destructive effect, even of large charges, under water.

This has a very important bearing on arrangements and systems for harbor defense. The necessary distances between permanent torpedoes are much greater than those within which the explosions are effective.

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* It is stated that it is the intention of the English experimenters to employ against the Oberon charges of 1,000 lbs. of gun-cotton.

It will not be an easy matter to obtain complete defense by means of permanent mines only. Lines of torpedoes must be separated from one another by large intervals. Firing by judgment cannot often be done with the accuracy required; so that dependence will generally be placed upon circuit-closers or breakers, or other automatic arrangements for firing or indicating position. Since explosions to be effective must occur very near the object, it will be possible for a vessel to remove or keep off these arrangements by means of "cradles," nettings, or other devices. Torpedoes which can be controlled and directed will be necessary to a complete system of defense.

In connection with the Oberon explosions, some experiments were made to observe the effect on contiguous charges. In one case two additional charges were used; one of 100 lbs. of wet gun-cotton was placed 100 ft. from the torpedo to be exploded; another of 50 lbs. of gun-cotton in a piece of netting was placed 120 ft. distant. Both rested upon a bed of soft mud. Neither was injured. In another case three outlying charges were buoyed at distances of 100 ft. from the main charge and from each other. One consisted of 50 lbs. of wet gun-cotton in a piece of netting, and another, of 50 lbs., of dynamite in tin cases. They were not exploded.

In some Swedish experiments charges of dynamite were exploded at distances of 100 ft. by the concussion from the explosion of another charge. Dynamite would probably be more sensitive to this action than gun-cotton.

At Carlscrona, Sweden, a series of experiments similar to those against the Oberon are being carried on by the Swedish and Danish Governments. The object attacked is a vessel provided with a Hercules double bottom, and it is intended to include the explosion of dynamite in direct contact with the double bottom. The details of these trials have not been published.

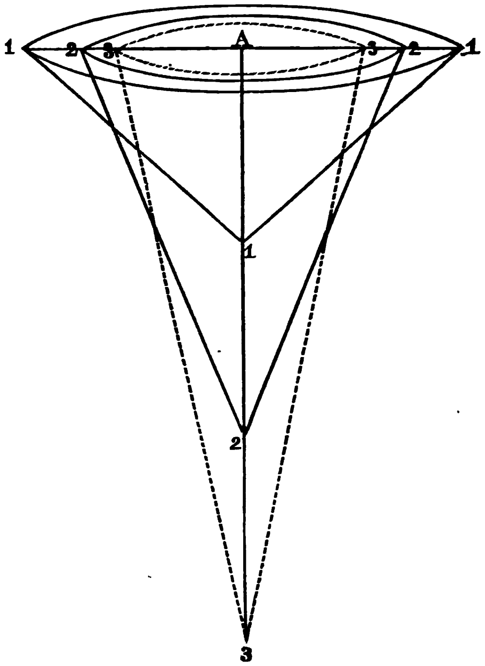
During the summer of 1874, a series of experiments were begun at this Station, which had in view the obtaining of some data in regard to the relation of depth to effective horizontal distance.

As the depth of water over a charge is increased the lateral extent of the explosion is diminished. It was proposed to determine the radius of explosive effect at various depths, and thence approximately the ratio of this diminution. In addition, it was thought that by the method used results might be obtained which could be employed in calculating actual or relative explosive force.

If a perfect explosion (detonation) of a given charge is produced, then the same force is exerted, or the same work done under any condition. The difficulty is to get any satisfactory mode of comparing detonating explosions with relation to the work done.*

Nitro-glycerine is a body which is certainly and readily detonated, and was therefore taken for these experiments.

When a charge of liquid nitro-glycerine is fired under water a violent shock is felt and the water over the charge is thrown out in the shape of an inverted frustum of a cone. This shape of the projected water is sharply defined. The idea was to measure the section of the column of water thrown out at the surface, and make this the means of comparison.



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* As Sprangel remarks, "it is to be regretted that no exact method yet exists for comparing the force of detonating explosions."—Jour. Chem. Soc., XI, 802.

The depth of water over a charge would be the altitude and the surface disturbance the base of a cone. As the depth is increased, using the same charge, the cone becomes more acute and *vice versa* The comparison of these cones of explosive effect would indicate the effect of depth, and the comparison of different charges at the same and different depths might give some data for calculating the force exerted.

In the figure (p. 58) the vertical line represents the depth and the horizontal line the surface. Then charges at the points 1, 2 and 3, on the vertical line, would give the cones of explosive effect 111, 222, and 333, respectively.*

Eight experiments were made. In each a charge of 50 lbs. of liquid nitro-glycerine was used. This was contained in a cylindrical wrought-iron case with cast-iron ends. Four ordinary electric (platinum wire) detonating fuses were used. The explosions were made in 138 feet of water.

Two large buoys were strongly anchored 250 feet apart. When an explosion was to be made the buoys were connected by a line which was then drawn taut. At about the middle of this line a float from which depended the charge was fastened. Movable buoys were attached to this line at such distances from the torpedo float as were found to be necessary to mark the limits of the disturbed or thrown-out water, and thus the diameter of the base of the cone could be measured.

The first experiment was made to obtain an estimated distance for placing the buoys. The depth of water over the charge was 30 feet; 75 feet was the distance fixed upon.

Four trials were made with the same charge (50 lbs.) at the same depth (30 feet.) The diameter of the disturbed area was the same in each case, nearly 70 feet.

In the next two experiments the same charge was fired at a depth of 60 feet. The diameter of the disturbed area was found to be 50 feet.

In another experiment the same charge was placed at 90 feet. At the first attempt the explosion was not accomplished. On examination it was found that under the great pressure of 90 feet nitro-glycerine had been forced into the fuses, saturating and rendering them useless. At the second attempt fuses heavily coated with gutta-percha were used, and no difficulty experienced with them. At this depth, however, very little surface effect was produced. Eighteen seconds after the jar of the explosion was felt, the water around the suspension buoy began to boil and assume a foamy appearance. The diameter of the foaming area was about 25 feet at first, but widened very rapidly.

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* It is hardly necessary to say that the figure is intended to represent only the position of the charges with reference to the disturbed areas.

In the figure, 1, 2 and 3 on the vertical line represent the positions of the charges at the depths of 30, 60 and 90 feet, and on the horizontal line, 11 and 22, the positions of the marking buoys for the 30 and 60 feet explosions. The dotted lines indicate the supposed similar effect of a 90-foot explosion, the one made being not considered, since, as might be expected, the charge was insufficient.

With 50 pounds of nitro-glycerine the surface disturbance at 30 feet is about double that at 60 feet. The force with which the smaller volume of water is thrown up diminishes with the depth, until at 90 feet that charge will not lift the water over it.

These experiments were of a preliminary character, in order to ascertain if corresponding results could be obtained under like circumstances. Many more must be made before any definite conclusions can be drawn from them. It was intended to continue them by using larger charges at the same and greater depths.

It was assumed that the radius of the disturbed area was the radius of explosive effect. Up to a certain depth it would be, but beyond that the increased mass of water smothers the explosion until it becomes entirely ineffective.

Then, as the depth increases beyond the most effective point, the disturbed area diminishes, and also the amount of force exerted over this area. This will be fully discussed on the completion of the experiments.

By comparing the explosions of different charges of the same or different bodies, some estimate of their relative force may be arrived at. It is possible, therefore, that if these trials are continued some useful conclusions may be reached.

It is intended to make other experiments at the same time, such as trials against hulks or targets, and other charges at various distances from those exploded.

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